

The use and benefits of computer mediated learning in teaching biology

F. Pamula, Y. Pamula, G.J. Wigmore and J.F. Wheldrake
The Faculty of Science and Engineering
The Flinders University of S.A.
F.Pamula@flinders.edu.au

Fred Pamula is interested in understanding the molecular mechanisms behind development of organisms. His other interests include understanding how students learn and how computers can be used to facilitate learning. Much of the literature on this subject suggests that there are only modest gains in using computers in teaching. Fred thinks that the major factor behind this lack of success is that the software used to write multimedia is at a primitive state of development. At present he is co-ordinator of the Computer Mediated Learning Unit in the Faculty of Science and Engineering at the Flinders University of South Australia.

Introduction

Of increasing concern among higher education institutions is the problem of maintaining the quality of education in the face of increased student numbers and continuing funding cuts. These concerns, coupled with the advent of readily accessible and relatively cost effective computer technology, has seen a marked increase in the use of computer-based education delivery systems in universities. Much debate now centres on how effective and beneficial computer-based learning (CBL) is, particularly with respect to learning and cognitive processes (Brown *et al.* 1989; Rowe 1993), student performance (Mevarech *et al.* 1991; Stewell and Delpierre 1992; Blackmore and Britt 1993; Mevarech 1993; Chambers *et al.* 1995), gender and age related performance (Massoud 1991; Lee 1993; Colley *et al.* 1994; Dyck and Smither 1994) and software design and mode of delivery (Ahern 1993; Jackson *et al.* 1993; Rowe 1993; Chambers *et al.* 1995). Addressing these questions is difficult due to a lack of published data and because comparisons of student performance are difficult given the highly diverse ways in which CBL is approached, implemented and evaluated.

One area to which CBL readily lends itself is the use of computer simulations in practical or laboratory teaching. Laboratory classes aim to teach students principles of experimental design, data collection, data processing as well as the correct usage of commonly used laboratory equipment. The application of computer simulations can be beneficial if (i) the costs of running a particular experiment are prohibitive (ii) time constraints apply *e.g.*, growth or breeding experiments (iii) ethical or humane considerations are involved *e.g.*, experiments involving euthanasia of large numbers of animals (iv) it is difficult to observe or manipulate the phenomenon under consideration *e.g.*, nutrient cycling in a plant community (v) it is important that students are familiar with a piece of equipment or procedure prior to undertaking an experiment *e.g.*, familiarity with the use of a spectrophotometer (vi) rapid and efficient feedback on a students understanding of the subject material is desirable (vii) the experiments are technically demanding (ix) require the use of dangerous or radioactive compounds. This talk will be primarily on the use of computer simulations in biology but I will talk about laboratory marking programs and tutorial assessment programs.

Spectrophotometry Simulation

The spectrophotometry simulation takes a novel approach to teaching the concepts of spectrophotometry since it provides a tutorial on the spectrophotometer, simulates experimental data and assesses the student's processing of the data. The program has

several parts. An introductory section presents instructions on how to proceed through the exercise. The sections that follow introduce the properties of light, the spectrophotometer, the Beer-Lambert law and finally the alcohol dehydrogenase assay which is used in the simulation. After reading through the tutorial, the student proceeds with the simulation and is asked to calculate the blood alcohol concentration for five patients using the Beer-Lambert law. The simulation presents the absorbances and the assay incubation time for the five patients measured using the alcohol dehydrogenase assay. The assay absorbance and sample volume are randomly generated, the absorbance ranges from 0.05 to 0.40 while the sample volume from 4 to 20 μl . The student's calculations are assessed by the program.

Advantages to the student

The delivery of content is consistent between classes because the human factor is largely removed from delivery of the material. Students can work through the material at their own pace, which is an advantage given that students have varying backgrounds and therefore the rate with which they acquire concepts varies from student to student. The background information provided in the computer simulations is designed to facilitate understanding of the simulation and often this is not the case when students are required to prepare for traditional experiments. More background information can be presented in a computer simulation than is possible in a traditional practical exercise and its presentation and delivery can be of a much higher standard because it is possible to use graphic images and animations to show dynamic processes. Interest in an exercise can be maintained by the judicious use of graphics and animations, which is usually not possible for traditional experiments. Students get immediate feedback as they progress through the exercise which is in marked contrast to traditional laboratory work. Although students have rostered computer sessions, they have fairly wide access to the computer suite so they can return to the programs when it is most convenient for them.

Advantages to the assessor

Assessment is more equitable and thorough as it is no longer subjective since the computer program follows well defined rules that are known at the outset of the exercise by the student and applied equally. Once a problem has been identified the student can seek help from the program or the tutor. The assessor is able to keep track of responses to individual questions thus evaluating any difficulties that students may be having with the material. Class results are easily and readily incorporated into a spreadsheet program thus saving time and costs in data entry. There are considerable savings in personnel costs associated with marking the simulations (especially in marking calculations) and the assessor is liberated of the tedium of marking.

Disadvantages

Of course as with all forms of teaching there are advantages and disadvantages. There are two important disadvantages (i) students forego valuable exposure to a laboratory environment and (ii) students are not exposed to preparing for experiments and performing the experiment. To offset this, it should be remembered that many students develop a disliking for experimental work because the experiments often do not work correctly. Although we have developed many simulation, it would be unwise to advocate the complete replacement of laboratory experiments with computer simulations because biology is an experimental science and as such the acquisition of skills in working in a laboratory is crucial.

Results

In our first year biology course we alternate between a wet and a dry practical exercise throughout the year. For some of the exercises (Table 1) the introduction of computer simulations has seen an improvement in grades (Spectrophotometry) and others a worsening of grades (DNA melting point).

Program	1993	1994
Spectrophotometry	74.6 (n = 245)	98.1 (n = 303)
DNA melting point	79.7 (n = 254)	74.3 (n = 304)
Genetics	77.8 (n = 250)	84.4 (n = 306)
Bacterial growth curve	68.7 (n = 233)	68.6 (n = 260)

Table 1. Mean final student marks for the four exercises in 1993 and 1994.

Fungicide Resistance Simulation

One of the great problems facing farmers and horticulturists is the management of fungicide resistance genes in populations of fungal pathogens. The understanding of this problem requires consideration of the ecology (epidemiology) of the fungus and the population genetics of the resistance genes. This computer simulation is intended to give the student insight into the population biology of the evolution of fungicide resistance by single gene mutations that give resistance to a specific fungicide. The student is able to vary the magnitudes of several parameters of the fungal population and the properties of the fungicide resistant mutant. This computer simulation was written because it is impossible to perform this kind of experiment in class.

Laboratory Marking Programs

Laboratory courses are very expensive to stage, not only in materials and equipment, but also in the personnel required to manage and assess them. A typical laboratory exercise requires students to collect, process and analyse experimental data. Unfortunately, the analysis of data by students is often flawed because the processing of experimental data is carried out in an unsatisfactory manner. To address the deficiencies outlined above, interactive computer programs were written to provide accurate and immediate feedback to students while they are processing experimental data. This approach was implemented in several laboratory exercise:

- Introductory exercise
- Glycolysis and fermentation of grape juice
- Induction of β -galactosidase in *Escherichia coli*
- Water relations in plants
- Genetics
- Purification of acid phosphatase

Although the steps involved in performing calculations from the observed and supplied parameters require only simple arithmetic operations, it has been our experience that a large proportion of students in second year classes encounter great difficulty in carrying out this process. This fact, combined with the relative simplicity of the calculations and the large class size (up to 200 students), meant that this laboratory exercise lent itself to a computer-aided learning approach. Students have unrestricted use of the computer program until the deadline for submission, which is usually two weeks after the laboratory exercise has been completed. At the end of this period, laboratory notebooks are collected and each student's data analysis is assessed while the student's computer record is used to assess the data processing component of the exercise. Assessment of this laboratory exercise is in two parts: (i) proficiency and accuracy in processing data and (ii) integrating and understanding experimental results. The two sections are weighted equally and passing grades are required in each section to get an overall passing grade for the exercise.

Advantages to the student

Breaking down a calculation into its steps guides a student through the calculation and promotes identification and remediation of errors. The program's interface requires the student to enter all data and answers to one group of calculations into a single data entry screen. In this way any inconsistencies in the calculations can be easily identified by the student with the aid of the program. Data entry screens facilitate editing so that any errors can easily be corrected. If errors are made, the student can make the appropriate corrections and have the work marked again. Enabling students to correct their work in this way encourages them to work at their own pace and strive for competency with the material.

On-line help is available, with textual and diagrammatic outlines of concepts required to solve a problem. Wherever possible, graphic images are used to illustrate textual explanations. Providing help in this way allows detailed explanations to be presented to the student without showing exactly how calculations are performed. If this assistance is not sufficient then students have recourse to tutors.

Advantages to the assessor

There are considerable savings in personnel costs associated with marking laboratory calculations using computer programs. The student record file can be retrieved directly into a spreadsheet program with minimal effort. The assessor is liberated from much of the tedium of marking laboratory notebooks and the quality of marking is made much more consistent and thorough.

The computer program has been written so that the assessor has access to the results generated by the program. This has two benefits: it allows rapid identification of the source of a student's error and it allows for quick and efficient spot checks of submitted laboratory notebooks. Being able to see the answers generated by the computer program when a student is having problems with a calculation enables rapid isolation of the source of the student's problem and to confirm whether the student has problems with other parts of the work.

Results

Although the approach outlined above has been successfully applied to several laboratory exercises at second year, the one we have most complete data is the exercise that explores the induction of β -galactosidase in *Escherichia coli*. Computer based assessment was first introduced for this exercise in 1993 but was not compulsory. The results (Table 2) show that students using the computer program scored much higher grades (81 %) than those assessed by tutors (66 %). In 1994 computer based assessment was compulsory for all students and the mark due to computer assessment was 94.6 % while the overall mark was 82.3 % (Table 2). The overall mark for the exercise was weighted equally between computer assessment and data analysis in 1994. The mark due to computer assessment for 1993 and 1994 was 76 and 94.6 % respectively. An analysis of the data was performed to determine if the results were biased towards males or females. In 1994, there were 63 female and 68 male students in the class and there does not appear to be any difference in the mark obtained by males and females either by computer assessment or overall (Table 2). The results also show that students spend about 5 hours using the computer marking program (Table 2). We estimate that they spend about an equal amount of time working on their calculations away from the program. If this estimate is correct students spend about 2.5 hours working on their calculations for every 3 hours practical session. Finally, about 84 % of student achieve grades of 91–100 % for their calculations (Table 3).

Parameters	1993 A	1993 B	1994 M	1994 F	1994	1995
Class size	128	33	68	63	131	169
Time spent (min)	—	—	—	—	—	209
Program usage range	—	1—18	1—16	1—14	1—16	1—16
Program usage	—	4.85	6.18	6.60	6.38	7.44
Program mark range (%)	—	16—100	39—100	24—100	0—100	0—100
Program mean mark (%)	—	76	94.4	94.9	94.6	94.8
Final mean mark (%)	66	81	81.4	83.3	82.3	83.0

Table 2. Grades achieved in the “Enzyme Induction in *Escherichia coli*” exercise in 1993-1995. In 1993 the use of the marking program was optional so the results are separated into hand marked (1993A) and computer marked (1993B). The final mark consists of the results from computer marking (if any) and the analysis of experimental data (from the laboratory note book). The columns 1994M and 1994F represent the 1994 data separated into male and female students, respectively. In 1994 the results also show the mean time students spent using the computer program.

Mark range (%)	Number of Students	%	Mark range (%)	Number of Students	%
0 — 10	0	0.0	51 — 60	3	2.3
11 — 20	0	0.0	61 — 70	3	2.3
21 — 30	2	1.5	71 — 80	3	2.3
31 — 40	1	0.8	81 — 90	9	6.9
41 — 50	0	0.0	91 — 100	110	84.0

Table 3. Frequency distribution of student marks in 1994 achieved in the computer assessed component of the exercise. The number of students and percentage of the class are given next to each mark range.

Tutorial Exercises Assessment

To gain proficiency in statistics it is necessary to apply the knowledge learnt in lectures to real problems. This has traditionally been done during tutorials but it has become more and more difficult to cope with large classes and the lack of motivation of students. To force student to work through the tutorials it was decided to grade them and these grades counted to the final assessment. In order to assess tutorial papers it was necessary to automate the assessment. To this end the preparation of unique tutorial questions and assessment was taken over by computer programs.

Program design

There are four components to the design. (i) generate test and sample data sets (ii) printing and distribution (iii) answer entry and (iv) assessment and posting of results. These points will be discussed in more detail below.

- A sample data set, questions and answers is prepared and distributed to students.
- A test data set which must be unique for each student, a common set of question is also distributed to each student.
- When students have completed their work they enter their answers into a program that records their answers. This program must place a time limit on data entry to discourage students from using valuable computer time in calculating their answers and prevent students trying to re-enter their work.
- After the deadline, the results file must be collected and processed and student results posted.

Results

Grades have improved since the introduction of graded tutorial exercises (Table 4) even though grades for the tutorial exercise represent a small part of the years work

Year	Enrolled	Passing	Pass rate (%)
1991	120	82	68
1992	191	106	55
1993	187	169	90
1994	137	118	86

Table 4. Final grades since 1991 in teaching statistics in biology. In 1993 computer assessment of tutorial work was introduced.

Summary

I have presented three strategies that have been developed to improve student learning outcomes in teaching undergraduate biology: computer simulations, laboratory and tutorial marking programs. Computer simulations that assess student work are used specifically in first year biology. Laboratory and tutorial marking programs are used exclusively in second year. In third year the use of software is more limited because we find it is not always economical to write the programs ourselves.

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